Chirp Control in Directly Modulated 25G PAM4 Transmitters for Optical Access Networks

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Abstract: Narrowband filtering chirp control is demonstrated for a 25Gb/s PAM4 signal in directly modulated transmitters for next generation optical access systems, allowing 50km transmission without chromatic dispersion compensation with blue-shift filtering offering the best performance.
OCIS codes: (060.2330) Fiber optics communications; (060.4080) Modulation

1. Introduction

The requirement to deliver high bandwidth content to both fixed and mobile broadband customers is driving the development of 100G capable access networks. For example, upcoming standards are considering passive optical networks (PONs) using 4 wavelengths with single lane rates of 25Gb/s. To date, PONs have generally employed non return to zero (NRZ) signaling; however, due to the high cost of 25G components more spectrally compact modulation formats such as 4 level pulse amplitude modulation (PAM4), which enable the reuse of cheaper 10G components, are now under consideration. While externally modulated transmitters are generally employed for PAM4 due to their superior performance, the use of directly modulated lasers (DMLs) would provide a more cost effective alternative, which is important especially for the customer side transmitter in PONs [1-4]. The performance of DML transmitters in the C-band is heavily limited by the interaction of laser chirp and fiber chromatic dispersion (CD). While electronic dispersion compensation [1,2], provides a solution suitable for optical access links, here we focus on an alternative solution with a simpler receiver implementation based on transmitter chirp control [3-5].

In this paper, the performances of DMLs with narrowband optical filtering at the transmitter for 25Gb/s PAM4 modulation using a 10G-class DML are investigated and compared to 25Gb/s NRZ using a 25G DML. The more common approach of controlling signal chirp using narrowband filters to suppress the red-shifted component of the signal (red-filtering) [3-5], is compared to a novel approach which uses the inverse filter slope to attenuate the blue-shifted components (blue-filtering) and create an amplitude inverted version of the signal. The latter exhibits superior performance, enabling the demonstration of 25Gb/s PAM4 transmission at 1538nm over 50km of standard single mode fiber (SSMF) with no pre or post compensation. The scheme is suitable for either PON upstream or downstream links due to the relatively simple structure of both the transmitter and the receiver.

2. Experimental results and discussion

The experimental system (Fig. 1a) comprises a 2-bit DAC for the generation of either a 12.5GBd PAM-4 signal or a 25Gb/s NRZ signal, with a PRBS15 pattern. A commercial 10G distributed feedback (DFB) DML with internal tunable narrowband optical filter (Finisar DM80-01) is used for 12.5GBd PAM4, whereas a high speed DML with 19GHz 3dB bandwidth (ExOptronics EX-DY7005-C) followed by an optical filter for chirp control is used for 25Gb/s NRZ, both emitting in C-band. Different lengths of SSMF are used before the receiver, which is a 10G PIN for the PAM4 signal and a 30GHz PIN for the NRZ case. Signals are captured with a digital storage oscilloscope (DSO) and analyzed offline. It should be noted that no pre or post equalization is performed on the signal.

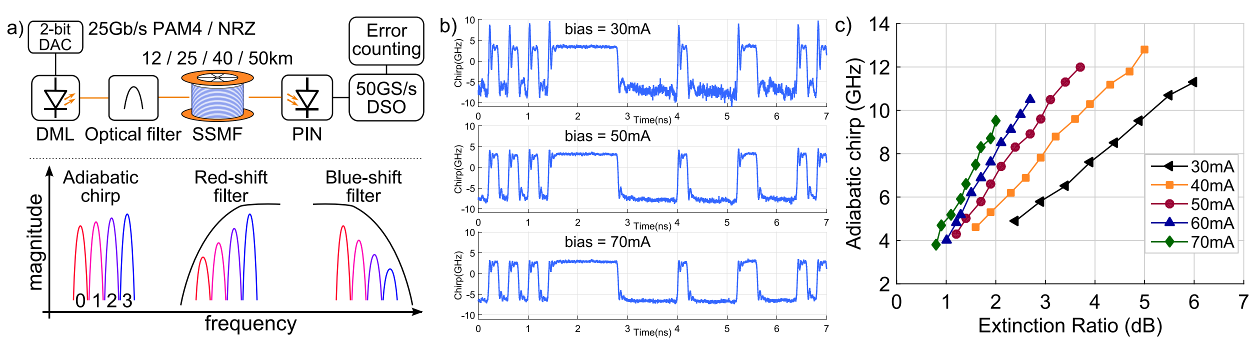

Fig. 1: (a) Experimental setup; (b) dynamic chirp traces for increasing bias; (c) adiabatic chirp as function of extinction ratio (NRZ case)

The two different types of DML chirp, adiabatic and transient, are characterized for different bias and amplitude of the driving signal. High extinction ratio (ER) modulation of DMLs is generally achieved by driving the laser close to threshold, which generates a high amount of transient chirp (Fig. 1b). On the other hand, if the bias current is well above threshold the transient chirp is greatly reduced, but the ER is lower. Adiabatic chirp also changes with the bias, but maintains a linear relation with the ER (Fig. 1c). The receiver sensitivity of the 25Gb/s PAM4 signal for a pre-FEC BER of 10^{-3} in optical back-to-back is only dependent on the ER and does not vary with the DML chirp and hence bias (Fig. 2a). However, after 12km of SSMF the transient chirp generated by operation close to threshold interacting with CD heavily distorts the signal and higher bias must be used to improve the sensitivity. The DMLs are thus biased at high current to suppress the transient chirp. This approach causes a low ER, but by using offset narrow optical filtering the different adiabatic chirped portions of the signal can be shaped to increase the ER. The 10G DML has an integrated multi-cavity filter which generates a 50GHz periodic passband response whose center frequency is temperature tunable. For the high speed DML an optical programmable filter with 1.6dB/GHz slope is used instead. Both filters are used in their linear region to preserve linearity of the signal and in particular equal symbols spacing for PAM4. Two solutions are proposed: the first, similar to the common approach used for NRZ [5], where the red-shifted lower energy symbols of the constellation are further suppressed; and the second, where the signal is logically inverted by applying a filter that heavily attenuates the blue-shifted higher energy symbols. The latter solution also inverts the adiabatic chirp to intensity level relationship.

The receiver sensitivities at 10^{-3} BER for the two filtering schemes were measured after different SSMF lengths for 12.5GBd PAM4 and the results are shown in Fig. 2b and Fig. 2c. Both solutions are able to operate at 50km with different optimum operating points. The signal with blue-filtering has poorer performance in back-to-back due to a slight linearity degradation, but it out-performs the conventional red-filtered chirp controlled signal for high CD with a 1.75dB sensitivity improvement at 50km. As a comparison, chirp managed 25Gb/s NRZ modulation (Fig. 2d) can achieve a similar performance to 12.5GBd PAM4 at 50km, but only by using more expensive 25G components. The best NRZ performance is obtained using a conventional chirp suppression scheme and for an optimum chirp value of half the baudrate [5]. It should also be noted that for PON applications further improvement in sensitivity can be achieved using an APD receiver. EDC and pre-distortion could also be used to increase the maximum chromatic dispersion tolerance and hence fiber length. Transmission of 25Gb/s PAM4 using the blue-shift chirp filter was performed with a 10G APD and 16 taps, 2 taps per symbol, FFE equalization at the receiver with a measured sensitivity of -21.2dBm after 50km of SSMF and -16.8dBm after 90km.

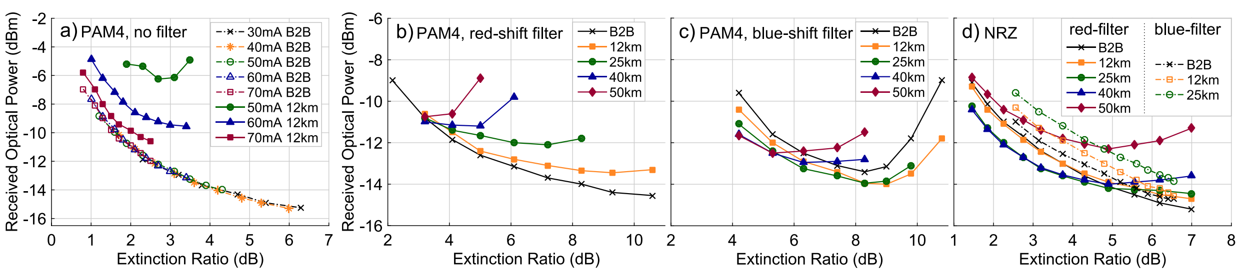

Fig. 2: DML sensitivity at BER 10^{-3} for: (a) 25Gb/s PAM4 without optical filtering; (b) 25Gb/s PAM4 with red-shift optical filter; (c) 25Gb/s PAM4 with blue-shift optical filter; (d) 25Gb/s NRZ for both optical filters.

3. Conclusions

Chirp management in DML transmitters has been demonstrated as a way to increase CD tolerance in fiber links using either 25Gb/s PAM4 or 25Gb/s NRZ modulation. Despite the more complex amplitude-chirp relationship chirp managed PAM4 shows similar performance to the conventional NRZ approach after transmission over 50km SSMF without any pre- or post-compensation. However, for next generation access network applications, the chirp managed PAM4 modulation scheme has the clear advantage of enabling the use of cheaper 10G components. Interestingly, best PAM4 performance is achieved when using blue-side filtering scheme, which effectively inverts the chirp to signal amplitude relationship compared to conventional red-side filtering.

4. Acknowledgements

We thank SFI Science Foundation Ireland (Grants 12/IA/I270 & 12/RC/2276) for funding this work.

5. References

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